

# A Review of Episodic Tremor and Slip (ETS) Observations in the Northern Cascadia Subduction Zone and Hazard Implications

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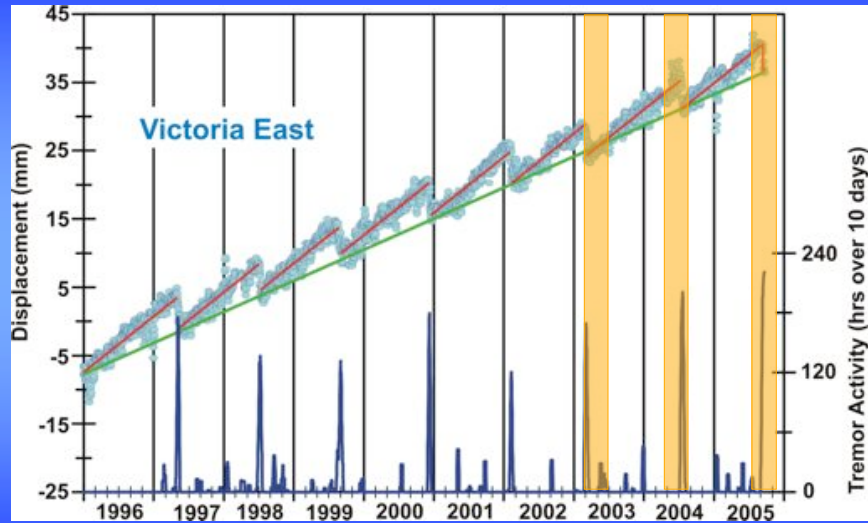


## What is Episodic Tremor & Slip (ETS)?

Currently defined empirically as:

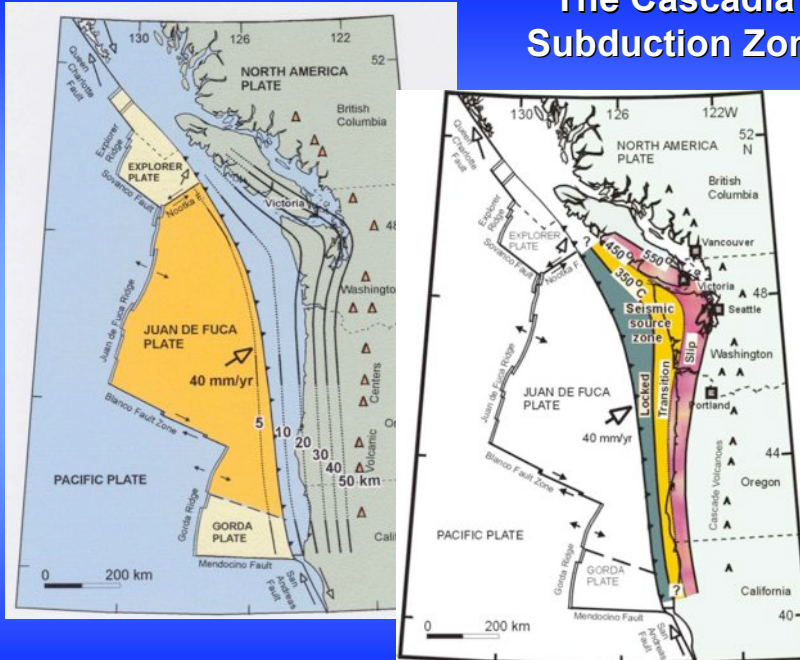
**Repeated, transient ground motions at a plate margin, roughly opposite to longer-term deformation, accompanied by emergent seismic signals in a narrow frequency band.**

## Continued Regularity of ETS in the Victoria Area

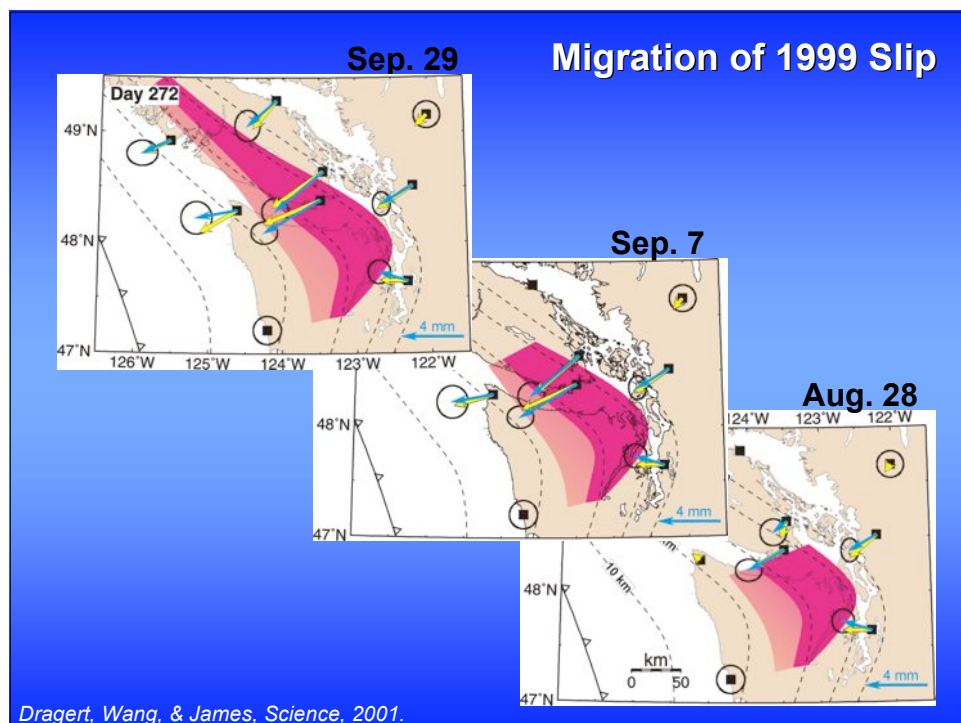


Orange bands show 2-sigma predicted time windows

## The Cascadia Subduction Zone

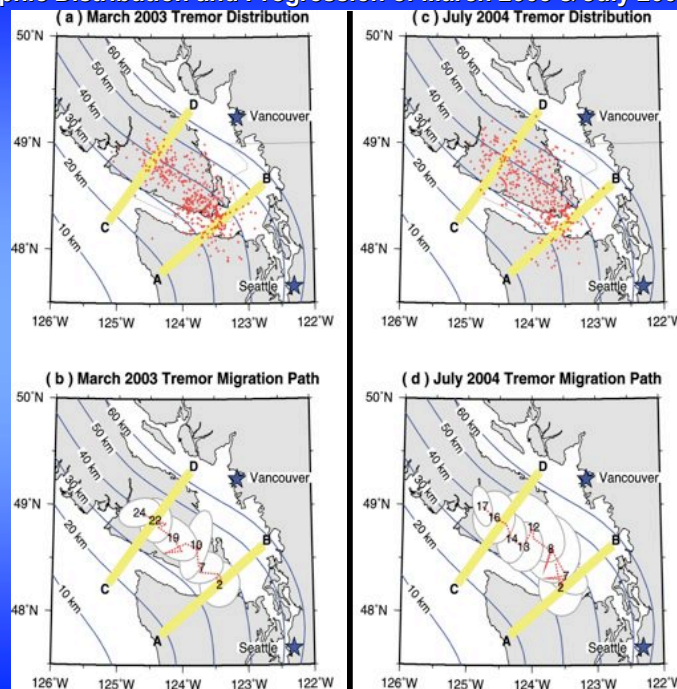


# The Slip

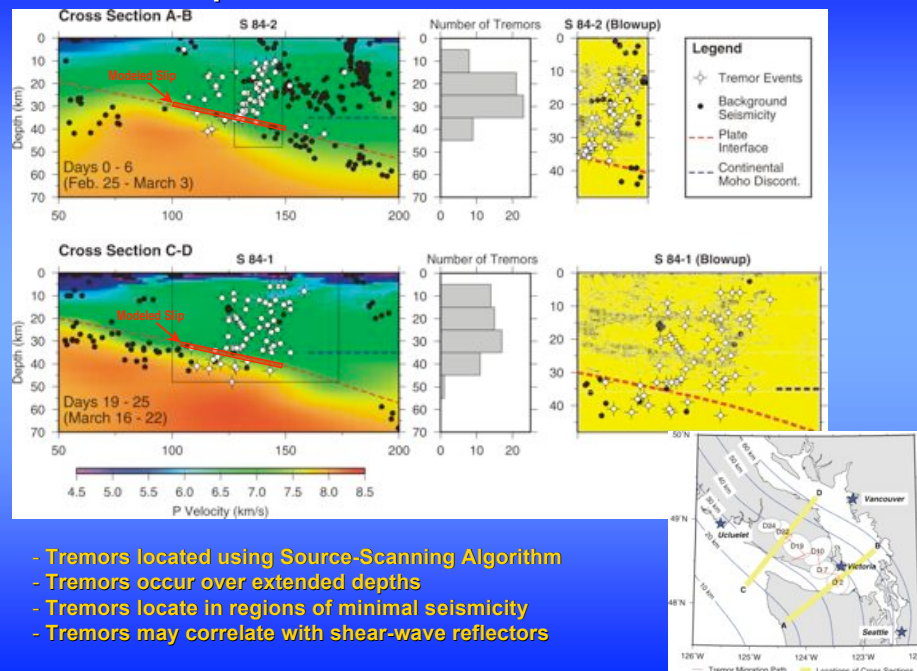


# The Tremor

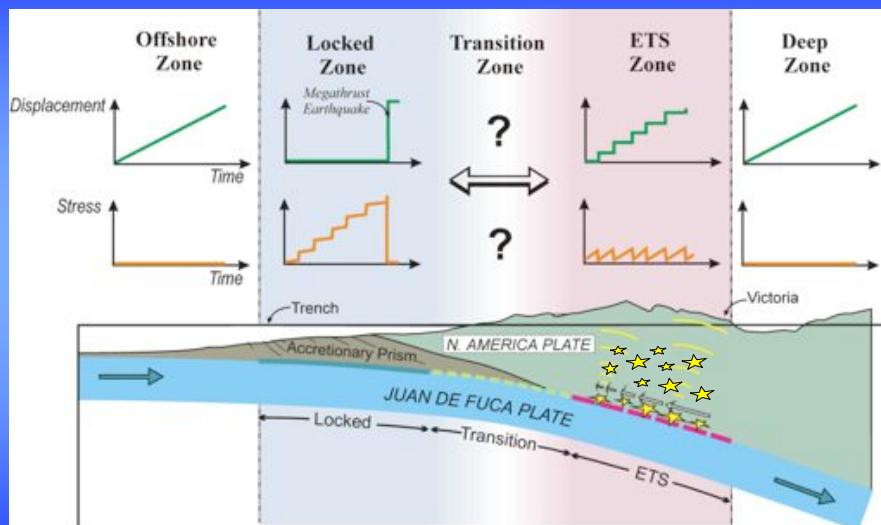
**Geographic Distribution and Progression of March 2003 & July 2004 Tremors**



## Depth Distribution of March 2003 Tremors



## Conceptual Model for Plate Motions & Stress Accumulation Across the Cascadia Subducting Plate Interface



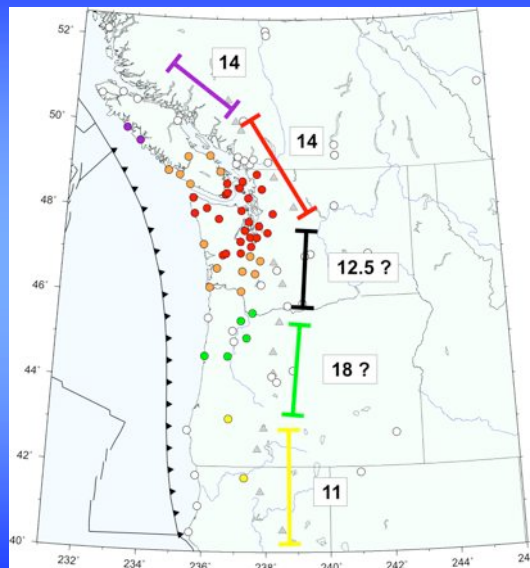
## ETS Impact on Cascadia Earthquake Probability

### ETS Segmentation and Recurrence

2 clear segments with 14  
month recurrence:  
- Northern Vancouver Island  
- Southern V.I.-northern Puget  
Sound

11 month period in northern  
California segment

Segmentation and recurrence  
unclear in northern Oregon  
and southern Washington



## ETS Impact on Cascadia Earthquake Probability

### Assumption:

- Cascadia PDF:  $N(552, 195)$

### Conditional probability:

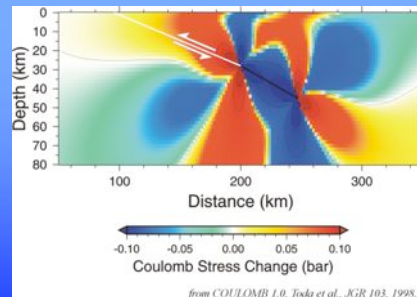
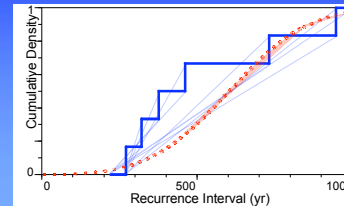
Next 50 years = 6%

Next Year = 0.1%

Next week = 0.002%

### Assumption:

- 5 ETS segments
- ETS: 2 weeks, 2/3 plate convergence
- ETS increases shear stress on seismogenic portion by 2/3 of annual loading
- Probability linear with stress increment



## ETS Impact on Cascadia Earthquake Probability

### Assumption:

- 5 ETS segments
- ETS: 2 weeks, 2/3 plate convergence
- Probability linear with stress increment

### (1) Treat Cascadia as a single zone:

Total ETS = 9 weeks / year

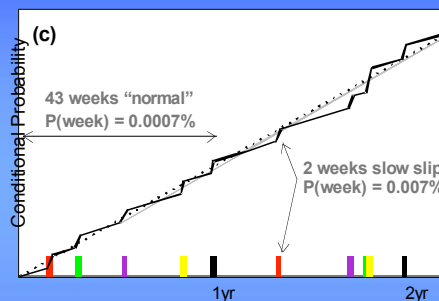
$$P_{CW}(ETS) = 0.0076\%$$

$$P_{CW}(no-ETS) = 0.0008\%$$

### (2) Treat Cascadia as 5 independent segments with their own recurrence period

$$P_{CW}(ETS) = 0.0074\%$$

$$P_{CW}(no-ETS) = 0.0007\%$$



### Conditional weekly probability:

ETS week ~10 times higher than no-ETS weeks



## CONCLUSIONS

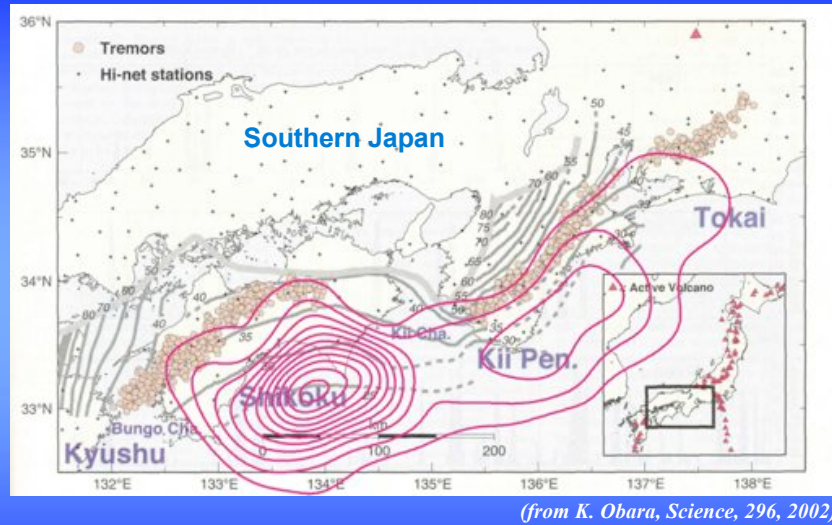
- \* Stress accumulates episodically across the deeper (25 to 45km) plate interface along the northern Cascadia Margin in the direction of plate convergence.
- \* For southern Vancouver Is. and northwest Washington, this deeper stress accumulation is relieved every 13 to 16 mo and the resulting surface displacements can be modeled by simple slip of a few centimeters on the deeper plate interface.
- \* This relief of stress, which occurs over periods of 2 or 3 weeks, is accompanied by distinct seismic tremors above the region of slip.
- \* This newly discovered behaviour may have significant implications for the landward extent and the timing of the next megathrust earthquake.



Extra Slides

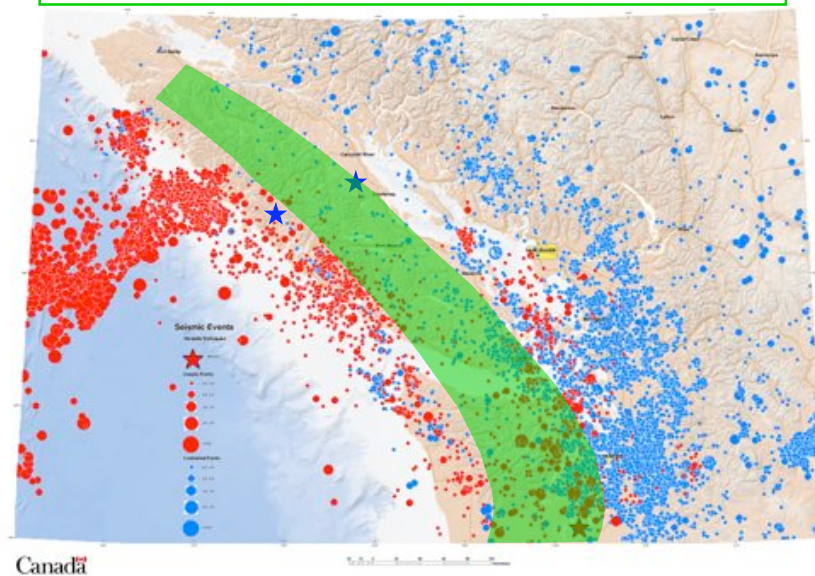


## Tremor Locations versus Megathrust Rupture



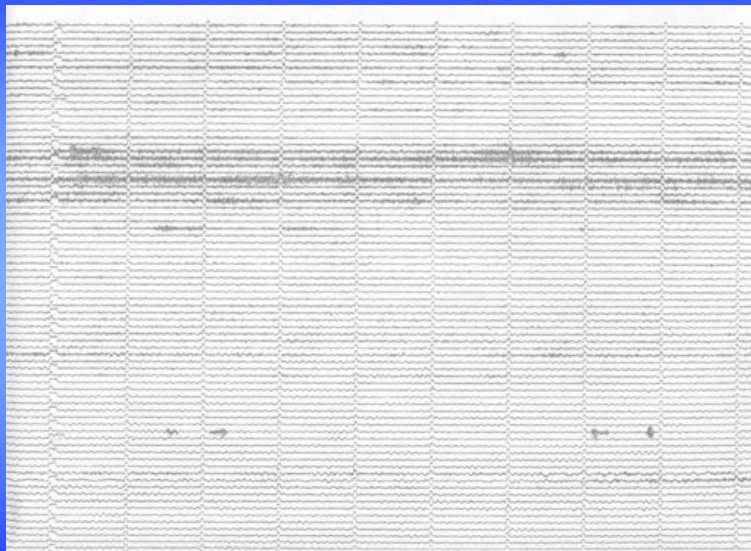
Smoothed distribution of coseismic slip (1 m contours) for the 1944 Tonankai and 1946 Nankaido earthquakes (from Sagiya & Thatcher, 1999)

## Region of Detected Tremors vs. Crustal Earthquakes



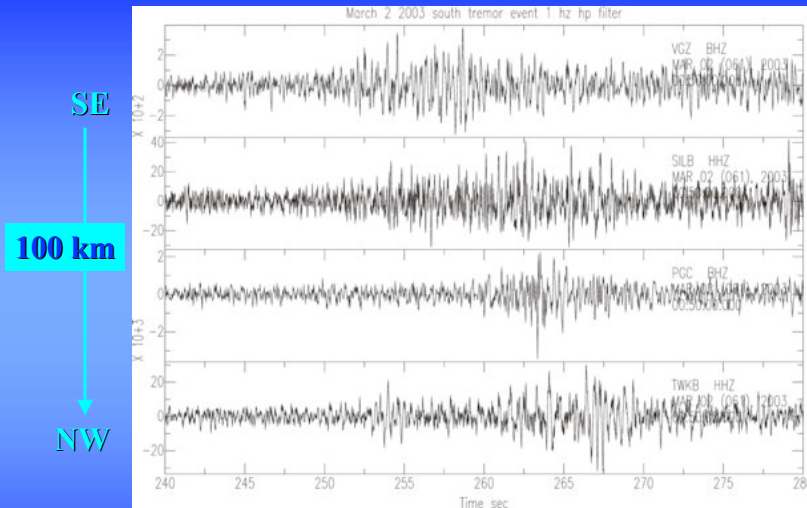


At typical recording speeds tremor appears as episodes of seismic “noise” at Vancouver Island Sites of the Canadian Seismograph Network



PGC sample chart showing typical record of seismic tremor

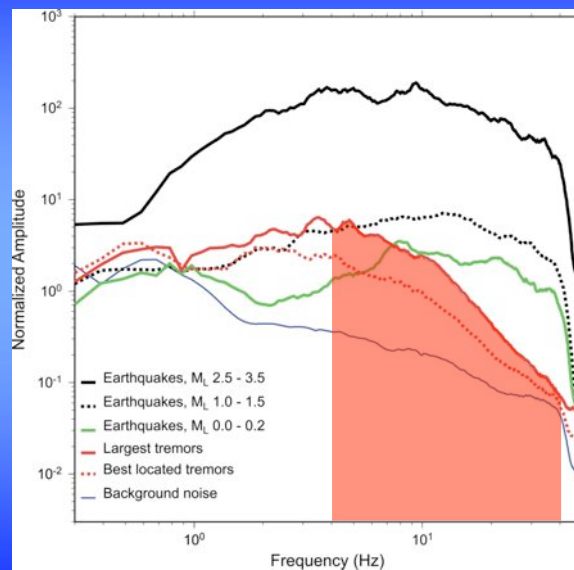
## Detailed Character of Tremor Activity



Mar. 2, 2003, South Region Tremor Event  
(1 Hz hp filtered vertical component at 4 sites)

Appears as low-frequency (1 to 5 Hz) noise bursts that move out coherently across the seismic network at shear wave velocity

## Comparison of Vertical Velocity Amplitude Spectra Averaged over Multiple Events for March 2003 ETS



*Kao et al., Nature, 2005*